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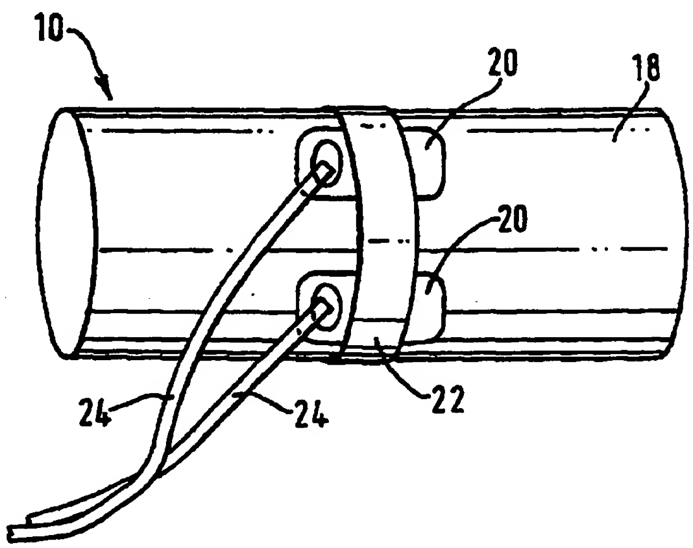

(57) Abstract

An electrical conductor for high-voltage (10 kV to 800 kV) windings comprises central conductive means and an outer semiconductive layer (18). At least one electrically conductive contacting device (20) penetrates into the outer layer (18), by means of a plurality of barbs, for grounding purposes. A single contacting device may contact a plurality of turns of the wound conductor. A method of establishing electrical contact with a semiconductive polymeric material comprises causing the contacting device to penetrate into the material.

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INSULATED ELECTRICAL CONDUCTOR FOR HIGH-VOLTAGE WINDINGS

The present invention relates to an insulated electrical conductor. More specifically, the invention relates to an insulated conductor, for use in high-voltage windings, having an outer layer of (at least semi-) conductive material which is contacted for grounding purposes. The conductor is intended to be used in large motors, generators and transformers at voltages in excess of 10 kV, in particular in excess of 36 kV, and preferably more than 72.5 kV up to very high transmission voltages, such as 400 kV to 800 kV or higher. In addition, the invention relates to a method of establishing electrical contact with (semiconductive) polymeric material.

A particular conductor which can be used in the invention is shown in cross section in Figure 1. The conductor 10 comprises strands 12, for example of copper, the majority of which are insulated, surrounded by a first conductive layer 14. An insulating layer 16, for example of cross-linked polyethylene (XLPE) surrounds the first conductive layer 14 and is in turn surrounded by a second conductive layer 18.

Whilst the layers 14, 18 are described as "conductive" they are in practice formed from a base polymer mixed with carbon black or metallic particles and have a volume resistivity of between 1 and 10^5 Ω·cm, preferably between 10 and 500 Ω·cm. Suitable base polymers for the layers 14, 18 (and for the insulating layer 16) include ethylene vinyl acetate copolymer/nitrile rubber, butyl grafted polythene, ethylene butyl acrylate copolymer, ethylene ethyl acrylate copolymer, ethylene propene rubber, polyethylenes of low density, poly butylene, poly methyl pentene and ethylene acrylate copolymer.

The first conductive layer 14 is rigidly connected to the

insulating layer 16 over the entire interface therebetween. Similarly, the second conductive layer 18 is rigidly connected to the insulating layer 16 over the entire interface therebetween. The layers 14 - 16 form a solid insulation system and are conveniently extruded together around the strands 12.

Whilst the conductivity of the first conductive layer 14 is lower than that of the electrically conductive strands 12, it is still sufficient to equalise the potential over its surface. Accordingly, the electric field is distributed uniformly around the circumference of the insulating layer 16 and the risk of localised field enhancement and partial discharge is minimized.

The potential at the second conductive layer 18, which should be zero or ground, is equalized at this value by the conductivity of the layer. At the same time, the conductive layer 18 has sufficient resistivity to enclose the electric field. In view of this resistivity, it is desirable to connect the conductive polymeric layer to ground at intervals therealong.

A problem experienced in making electrical contact with polymeric layers is that they expand in use, due to their high thermal expansion coefficient, and also creep under mechanical loading.

It is an object of the invention to maintain the second conductive layer substantially at ground by providing a suitable contacting device.

Accordingly, the present invention provides an electrical conductor for high voltage windings, comprising central conductive means and an outer semiconductive layer, characterised in that at least one electrically conductive contacting device penetrates into the outer semiconductive layer.

In a preferred embodiment, the central conductive means comprises one or more strands of wire, which are surrounded in turn by an inner layer of lower conductivity than the wire, then by an electrically insulating layer, and then by the outer layer which preferably has a higher conductivity than the insulating layer.

In an embodiment of the invention, the contacting device is metallic and comprises a substantially planar member having a plurality of barbs which penetrate into the semiconductive layer. The barbs may have re-entrant portions for engaging the semiconductive layer. The barbs may be of shape-memory metal.

A plurality of contacting devices may be provided at different points on the surface of the conductor. The contacting devices may be secured on the conductor surface by at least one resilient band, and for example several bands may each secure a plurality of the devices.

A single contacting device may penetrate into the outer semiconductive layer of a plurality of conductors or of a plurality of turns of a wound conductor. Biassing means, for example, one helical spring for each turn, is preferably used to urge said single contacting device into engagement with the turns.

One or more grounding wires may be connected, for example soldered, to the or each contacting device.

The present invention also provides a method of establishing electrical contact with semiconductive polymeric material, comprising causing an electrically conductive contacting device to penetrate into the material.

One embodiment of the method comprises placing a substantially planar contacting device on the surface of the polymeric material and punching out portions of the device

such that said portions penetrate into the material. These steps are not necessarily carried out in the order stated above.

An alternative embodiment comprises accelerating the contacting device towards the semiconductive polymeric material, for example by firing it from a gun means. The method may include a preliminary step of heating the polymeric material, at least in the region to be contacted.

If the polymeric material is a semiconductive outer layer of an electrical conductor, a plurality of contacting devices may be connected thereto and the method may include connecting at least one grounding wire to the or each contacting device, for example by soldering.

The present invention is particularly convenient for rapidly connecting a large number of reliable and durable contacting devices to the outer semiconductive polymeric layer.

Embodiments of the invention will now be described in more detail, by way of example only, with reference to the accompanying drawings, in which:-

Figure 1 is a transverse section through a conductor according to the invention, but not showing the contacting device;

Figure 2 is a schematic perspective view showing a first embodiment of contact device mounted on the conductor of Figure 1;

Figure 3 shows a tool for use with the embodiment of Figure 2;

Figure 4 is a schematic section of a second embodiment of contact device mounted on a plurality of turns;

Figure 5 is a schematic section of a third embodiment of contacting device mounted on the conductor;

Figure 6 is a diagram showing the distribution of barbs on the contacting device of Figure 5;

Figure 7 is a side view of a fourth embodiment of contacting device;

Figure 8 is a schematic section showing the contacting device of Figure 7 mounted on the outer polymeric layer; and

Figure 9 is a diagram showing the distribution of barbs on the contacting device of Figure 7.

Figure 2 shows two contacting devices 20 mounted to the outer polymeric layer 18 of the conductor 10. The contacting devices 20 are preferably of silver or silver-clad copper and each comprises a substantially planar member.

Prior to connecting the devices 20, the surface of the semiconductive polymeric layer 18 can be degreased, roughened and/or sprayed with a silver spray. Each contacting device is then placed on the surface of the layer. A tool 30, shown in Figure 3, is then used to punch out portions of the planar member. The punched-out portions penetrate into the polymeric material, increasing the contact surface, and additionally causing the silver spray to penetrate the material. The contacting devices 20 then have a "grater" surface.

Alternatively, prior to applying the planar member to the layer 18, this member can be shaped using the tool to punch out the portions or barbs and the thusly formed contacting device can be pressed or fired into the layer 18.

A strip spring or watch spring 22 is used to secure the contacting devices 20 to the conductor 10, and a grounding lead 24 is soldered to each contacting device 20.

Figure 4 shows how a single contacting device 40 having a "grater" surface can be used to rapidly contact a number of turns 42 of the conductor 10. The contacting device 40 is laid across the turns 42, which abut each other. Springs 44 (one spring for each turn 42) urge the contacting device 40 to penetrate into the outer layer. The springs 44 are placed against a support 46 which may, for example, form part of the housing of a machine or transformer.

Figure 5 shows a third embodiment of contacting device 50, comprising a planar member 52 having re-entrant barbs 54 which operate in the manner of fish-hooks. The barbs 54 are preferably resilient or of shape-memory metal. In the latter case they can unfold after insertion into the polymeric layer 18. Figure 6 schematically shows the distribution of the barbs 54 on the contacting device 50.

Figures 7 to 9 show a fourth embodiment of contacting device 60 having two rows of diverging barbs 62. The barbs are advantageously of shape-memory metal and are bent so as to diverge further when they penetrate into the semiconductive polymeric layer 18, as shown in Figure 8.

Prior to connecting any of the contacting devices of the invention to the conductor, the latter can be heated locally to soften the polymeric layer and facilitate insertion of the barbs. The devices 50, 60 can be shot into the polymeric layer using a tool similar to a nail gun.

The contacting devices of the invention provide a large number of uniformly distributed points of contact on the external semiconductive layer and adhere well thereto. This guarantees a low and uniform current density, if earth current flows. Electrical contact is established easily and rapidly and remains stable over a long period of time.

The conductor of the invention may alternatively be a superconductor in which the central conductive means comprises

superconductive material.

The electrical insulation of an electrical conductor according to the invention is intended to be able to handle very high voltages, e.g. up to 800 kV or higher, and the consequent electric and thermal loads which may arise at these voltages. By way of example, electrical conductors according to the invention may comprise windings of power transformers having rated powers from a few hundred kVA up to more than 1000 MVA and with rated voltages from 3 - 4 kV up to very high transmission voltages of from 400 - 800 kV or more. At high operating voltages, partial discharges, or PD, constitute a serious problem for known insulation systems. If cavities or pores are present in the insulation, internal corona discharge may arise whereby the insulating material is gradually degraded eventually leading to breakdown of the insulation. The electric load on the electrical insulation in use of an electrical conductor according to the present invention is reduced by ensuring that the inner layer of (semi)conductive material of the insulation system is at substantially the same electric potential as conductors of the central electrically conductive means which it surrounds and the (semi)conductive outer layer is at a controlled, e.g. earth, potential. Thus the electric field in the electrically insulating layer between these inner and outer layers is distributed substantially uniformly over the thickness of the intermediate layer. By having materials with similar thermal properties and with few defects in these layers of the insulation system, the possibility of PD is reduced at given operating voltages. The electrical conductor can thus be designed to withstand very high operating voltages, typically up to 800 kV or higher.

CLAIMS

1. An electrical conductor for high-voltage windings, comprising central conductive means and an outer semiconductive layer, characterised in that at least one electrically conductive contacting device penetrates into the outer semiconductive layer.

2. A conductor according to claim 1, wherein the central conductive means comprises one or more strands of wire, and is surrounded in turn by an inner layer of lower conductivity than the wire, then by an electrically insulating layer and then by the outer polymeric layer.

3. A conductor according to claim 1 or 2, wherein the outer layer comprises at least one polymer and carbon black, and has a volume resistivity of between 1 and 10^5 $\Omega\cdot$cm.

4. A conductor according to claim 3, wherein the resistivity of the outer layer is between 10 and 500 $\Omega\cdot$cm.

5. A conductor according to claim 1, 2, 3 or 4, wherein the contacting device is made from, or clad with, a noble metal.

6. A conductor according to any one of the preceding claims, wherein the contacting device comprises a substantially planar member having a plurality of penetrating barbs.

7. A conductor according to claim 6, wherein the barbs comprise punched-out portions of the planar member.

8. A conductor according to claim 6, wherein the barbs have re-entrant portions engaging the semiconductive layer.

9. A conductor according to claim 6 or 8, wherein the barbs are of shape-memory metal.

10. A conductor according to any one of the preceding claims, wherein a plurality of contacting devices are provided at different points on the surface of the conductor.

11. A conductor according to claim 10, wherein at least two of said contacting devices are secured on the conductor surface by a resilient band.

12. A conductor according to any one of claims 1 to 10, wherein the or each contacting device is secured on the conductor surface by a resilient band.

13. A conductor according to any one of claims 1 to 10, wherein the conductor is wound in a plurality of turns and a single contacting device penetrates into the outer semiconductive layer of at least two of said turns.

14. A conductor according to any one of the preceding claims, wherein at least one grounding wire is connected to the or each contacting device.

15. A conductor according to any one of the preceding claims, characterised in that the electrically conductive means and outer semiconductive layer are designed for high voltage, suitably in excess of 10 kV, in particular in excess of 36 kV, and preferably more than 72.5 kV up to very high transmission voltages, such as 400 kV to 800 kV or higher.

16. A conductor according to any one of the preceding claims, characterised in that the electrically conductive means and outer semiconductive layer are designed for a power range in excess of 0.5 MVA, preferably in excess of 30 MVA and up to 1000 MVA.

17. A contacting device for establishing electrical contact with a semiconductive polymeric material, comprising means for penetrating into the semiconductive polymeric material.

18. A contacting device according to claim 17, wherein the penetrating means comprises a plurality of barbs depending from a substantially planar member.

19. An assembly comprising a plurality of electrical conductors, each comprising central conductive means and an outer semiconductive polymeric layer, and a contacting device comprising a substantially planar member and a plurality of barbs penetrating into the outer semiconductive polymeric layers of the conductors.

20. An assembly according to claim 19, including biassing means for urging the contacting device into engagement with the outer semiconductive polymeric layers.

21. A method of establishing electrical contact with a semiconductive polymeric material, comprising causing an electrically conductive contacting device to penetrate into said material.

22. A method according to claim 21, comprising placing a substantially planar contacting device on the surface of the semiconductive polymeric material and punching out portions of the device such that said portions penetrate into the material.

23. A method according to claim 21, wherein the contacting device has barbs and the method comprises forcing the barbs into the material.

24. A method according to claim 21 or 23, comprising accelerating the contacting device towards the material using gun means.

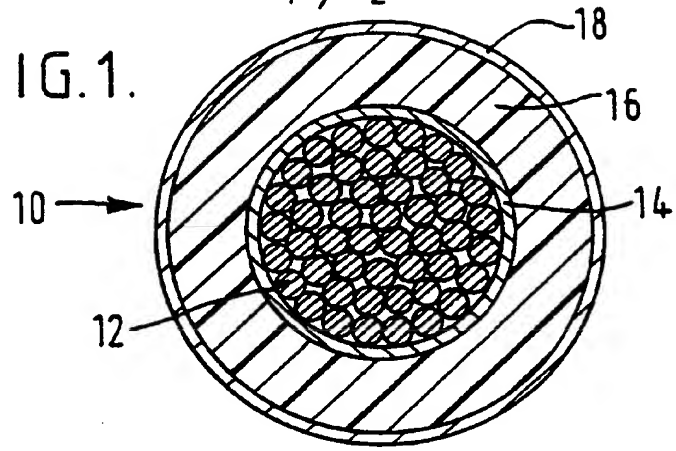
25. A method according to claim 21, 22, 23 or 24, including a preliminary step of heating the semiconductive polymeric material at least in the region to be contacted.

26. A method according to any one of claims 21 to 25, wherein the semiconductive polymeric material is a semiconductive outer layer of an electrical conductor.

27. A method according to claim 26, comprising connecting a plurality of contacting devices to the polymeric material.

28. A method according to claim 26 or 27, including connecting at least one grounding wire to the or each contacting device.

FIG.1.



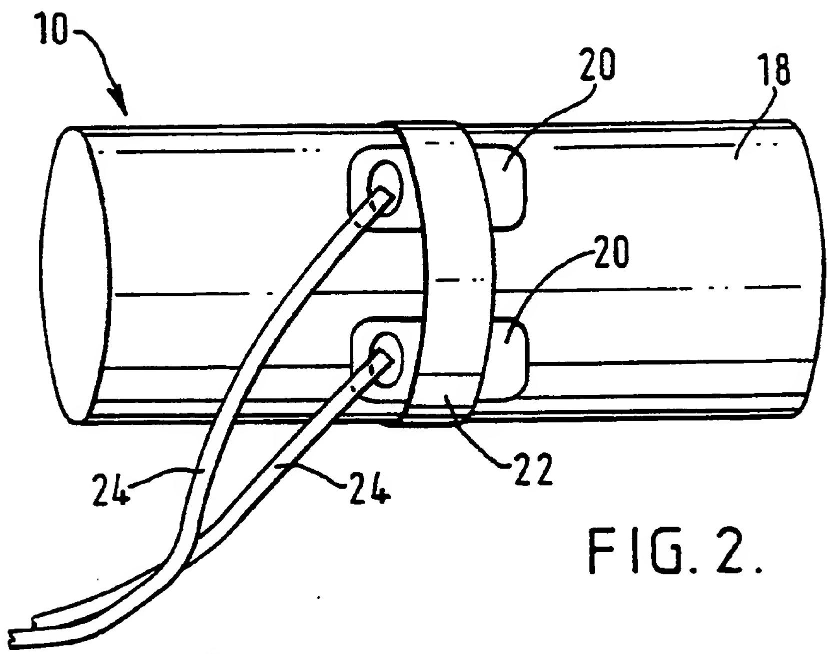


FIG. 2.

FIG. 3.

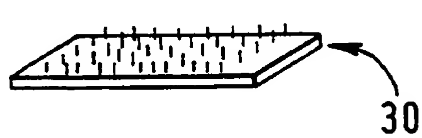


FIG. 4.

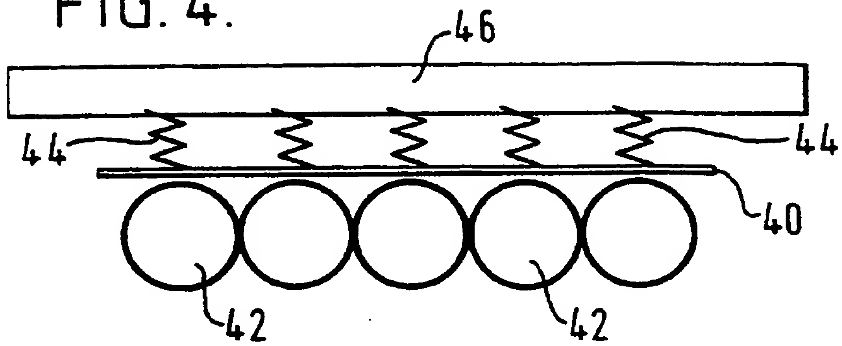
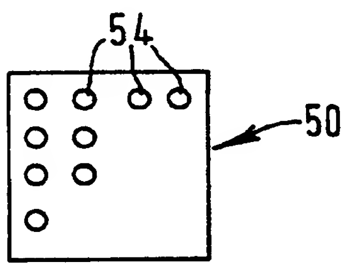


FIG.6.



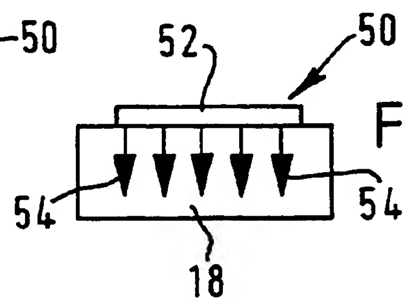


FIG. 5.

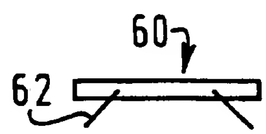
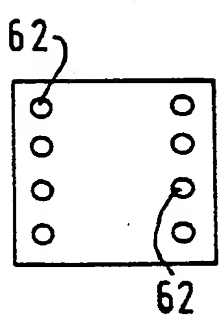


FIG. 7.

FIG.9.



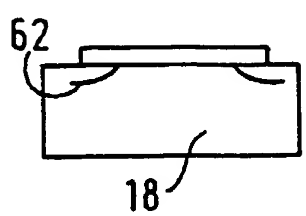


FIG. 8.